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Stator Resistance Estimation Utilizing Real and Reactive Power for Direct Torque Controlled Induction Motor Drives

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ABSTRACT: In this paper, a new method is proposed to estimate the Stator Resistance for direct torque control of Induction Motor. Direct Torque control of Induction Motor (IM) requires accurate estimation of torque, flux angle and resultant flux and these signals in turn depends on the motor flux. The flux is generally estimated using voltage model equations. The voltage model equation to a large extent depends on the accuracy of stator resistance of the induction motor. The stator resistance varies due to temperature during motor operation. Hence a method based on the active and reactive power is proposed for stator resistance estimation. The effect of stator resistance variation on the flux, torque and flux angle is studied and the results obtained are presented. The proposed method of stator resistance estimation is shown to track the various %changes in stator resistance with good accuracy.

KEYWORDS: Stator Resistance Estimation, Active power, Reactive Power, Induction Motor, Direct Torque Control (DTC), Flux estimator.

I.INTRODUCTION

Induction motor is popularly used for many applications because its construction is simple and it requires less maintenance [1]-[4]. Recent advances in power semiconductor and Microprocessor technology has made possible the application of advanced control techniques to alternating current (AC) motor drive systems. Direct Torque Control (DTC) has become a popular technique for the control of induction motor (IM) drives as it provides a fast dynamic torque response [5], [6]. The performance of DTC to a large extent depends on the knowledge of feedback signals namely torque, flux angle and resultant flux. These signals in turn depend on the accuracy of flux estimation. The voltage model is generally preferred for flux estimation as it requires voltage and current for computation. The voltage model equations depend on the stator resistance. The Stator resistance varies with temperature during the motor operation and introduces error in flux estimation. This in turn introduces large error in the flux angle and torque. This would deteriorate the overall performance of the drive. Hence on-line estimator is required to track variation in stator resistance. Numerous methods for stator resistance estimation are proposed in the literature and it forms an active area of research. The stator resistance estimation utilizing the rotor flux error is proposed [7]. Model reference adaptive system scheme with stator current as state variable is proposed in [8], [9]. The neuro-fuzzy method utilizing stator current is proposed in [10]. The observer based technique utilizing the stator current is proposed [11]. Recently, power based methods are becoming popular. A method using real power is proposed in [12]-[14]. A method utilizing both real and reactive power is proposed [15]. This method is applied only for temperature monitoring of the machine and not applied for drives applications. In this paper, the same approach is applied for stator resistance estimation for flux estimator in direct torque controlled IM drives which is the novelty of this paper. The models are built in MATLAB/Simulink. The proposed method is shown to track variation in stator resistance very well with good accuracy through simulation.

II.DIRECT VECTOR CONTROLLED IM DRIVES

The direct torque control of induction motor showing the importance of stator resistance is presented in Fig. 1. In DTC drive systems, the feedback signals namely flux angle, resultant flux, torque required for control are computed from the equation (1)-(3). The feedback signals depend on the stator flux and it is estimated using voltage model equations (4) and (5). The stator resistance required for proper functioning of flux estimator is given from the stator resistance estimator. The DTC motor drive system become unstable when the set value of the stator resistance used in the flux

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estimator differs from the actual value. The effect of stator resistance variation on the instantaneous fluxes, flux angle, torque is studied. For the study, 50% step change in the stator resistance is applied at 1sec. The investigation is carried out at a low frequency under the load torque of 1Nm as the stator resistance variation is more significant at low frequency. The d and q-axis fluxes, flux angle, torque obtained are presented in Fig. 2, Fig. 3, Fig.4 and Fig.5 respectively. From the results obtained, it is observed that as soon as the step change in stator resistance is applied at 1 sec, the d-axis flux, q-axis flux, flux angle and electromagnetic torque deviates from the actual. This in turn leads the drive system become unstable. This necessitates the need for stator resistance estimator.

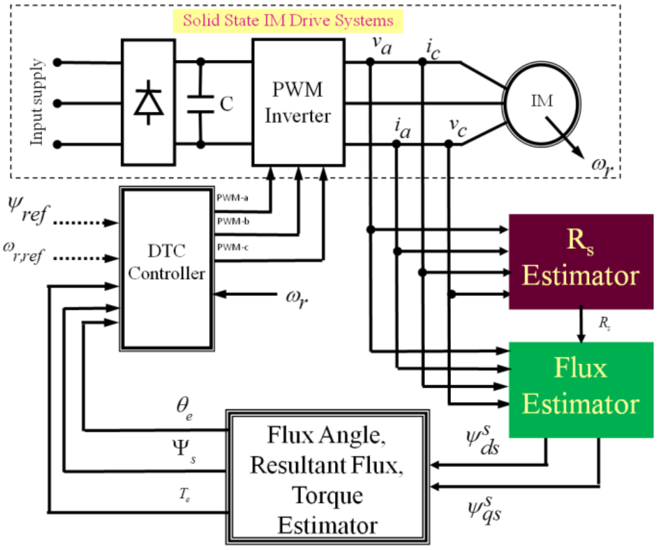

Fig. 1. Basic block diagram of DTC Showing the importance of Stator Resistance Estimator

Fig. 1 describes the importance of various estimators in direct torque controlled IM drives especially stator resistance estimator. The correct stator resistance estimation assumes importance for the proper operation of the drive. If there is a mismatch between the value of the stator resistance in flux estimator and the actual value in the machine, then this will introduce error in the fluxes and this in turn introduces error in the feedback signals namely flux angle, resultant flux and torque. This leads to performance deterioration of the complete drive system.

$$\theta_e = \tan^{-1}\frac{\psi_{qs}}{\psi_{ds}} \tag{1}$$

$$\psi_s = \sqrt{\psi_{ds}^2 + \psi_{qs}^2} \tag{2}$$

$$T_e = \frac{3P}{4}\left(\psi_{ds} i_{qs} - \psi_{qs} i_{ds}\right) \tag{3}$$

$$\psi_{ds}^s = \int \left(V_{ds}^s - R_s I_{ds}^s\right) dt \tag{4}$$

$$\psi_{qs}^s = \int \left(V_{qs}^s - R_s I_{qs}^s\right) dt \tag{5}$$

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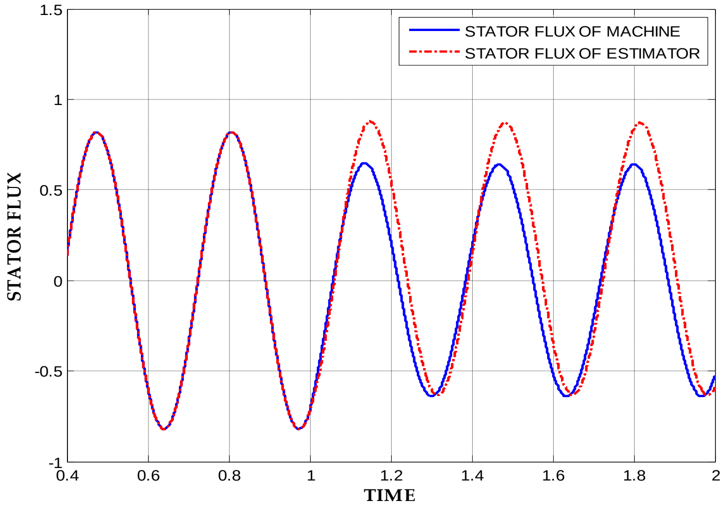

Fig.2. d-axis stator flux

Fig. 2 shows the d-axis rotor flux for stator resistance variation. The curve indicated in blue colour is the actual and the curve indicated in red colour is the estimated one. The d-axis flux tracks the actual flux when the value of stator resistance in the flux estimator matches with the actual one. When there is a mismatch at 1sec, the estimated d-axis flux fails to track the actual.

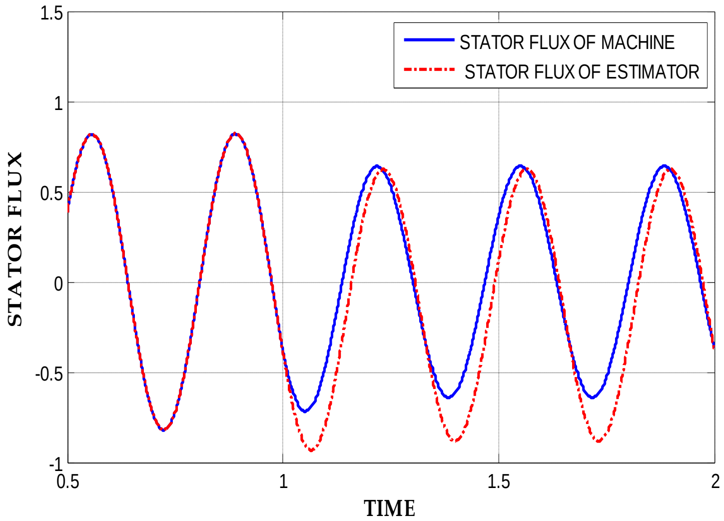

Fig.3.q-axis Stator flux

Fig. 3 shows the q-axis rotor flux for stator resistance variation. The curve indicated in blue colour is the actual and the curve indicated in red colour is the estimated one. Similar performance is observed as in the case of d-axis flux.

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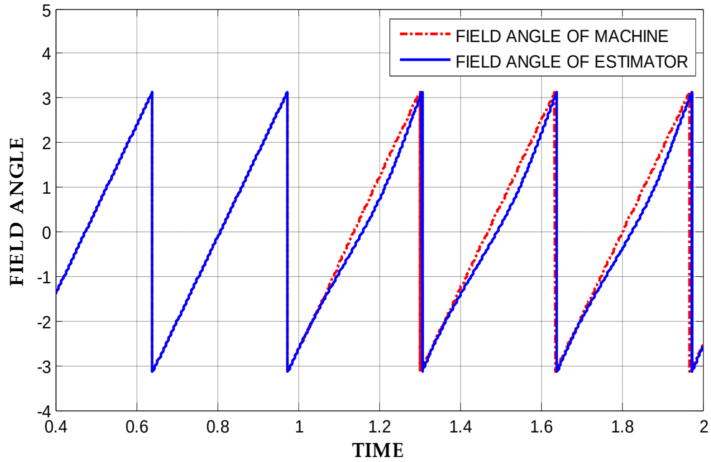

Fig.3.Flux Angle

Fig. 4 shows the flux angle for stator resistance variation. The curve indicated in blue colour is the actual and the curve indicated in red colour is the estimated one. The flux angle deviates from the actual when there is change in stator resistance at 1sec.

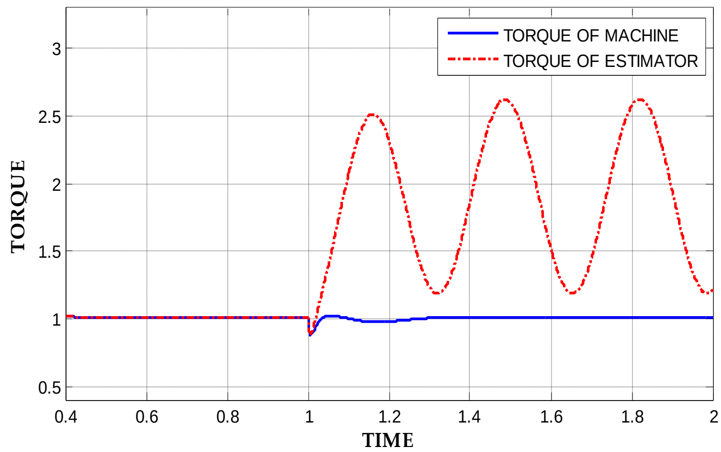

Fig.5. Electromagnetic Torque

Fig. 5 shows the resultant flux for stator resistance variation. The curve indicated in blue colour is the actual and the curve indicated in red colour is the estimated one. The resultant flux also deviates from the actual and oscillation is observed, when there is change in stator resistance at 1sec.

III. PROPOSED METHOD

The proposed method uses both real and reactive power of the motor [15]. The stator resistance can be estimated using the equation (6)-(9)

$$R_s = \frac{P}{I_{\max}^2} - \sqrt{\left(\frac{Q}{I_{\max}^2} + \omega L_s\right)\left(\frac{\omega M^2}{L_r} - \frac{Q}{I_{\max}^2} - \omega L_s\right)} \qquad (6)$$

$$P = V_{ds} I_{ds} + V_{qs} I_{qs} \qquad (7)$$

$$Q = V_{ds} I_{qs} - V_{qs} I_{ds} \qquad (8)$$

$$I^2{}_{\max} = I_{ds}^2 + I_{qs}^2 \qquad (9)$$

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IV. STATOR RESISTANCE ESTIMATION USING PROPOSED METHOD

The performance of estimator designed using the proposed method is tested for various %changes in stator resistance. The motor is modelled using d-q dynamic model equations to incorporate variation in the stator resistance. The step change in stator resistance is effected at 2 sec. The step change is the worst case condition used to show the ability of the proposed estimator to track variation in parameter even in the extreme case condition. The results obtained for 10%, 30% and 50% change is presented in the Fig. 6, Fig. 7 and Fig. 8 respectively. The %error and settling time for various %changes in stator resistance is consolidated and presented in Table 1. From the results obtained, it is clear that the proposed stator resistance estimator estimate the stator resistance with the maximum Error and settling time of 0.36% and 0.5 sec.

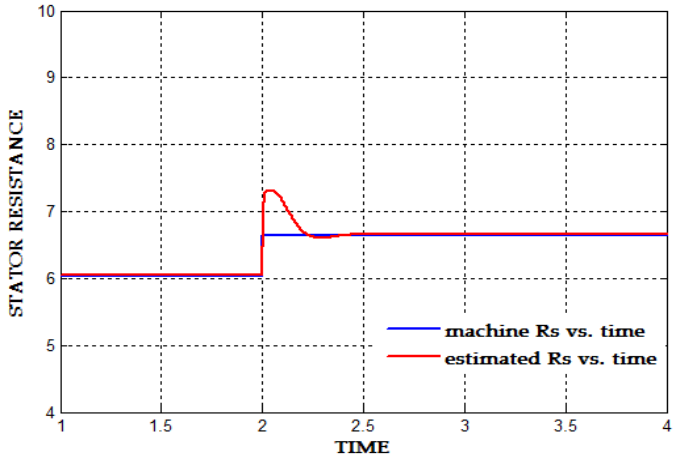

Fig.6. Actual and Estimated Stator Resistance for 10% change in R_s

Fig. 6 shows the performance of proposed stator resistance estimator for 10% change. The curve indicated in blue colour is the actual and the curve indicated in red colour is the estimated one. The estimated stator resistance closely tracks the actual one very well and settles down quickly as soon as the step change in stator resistance is effected at 1 sec.

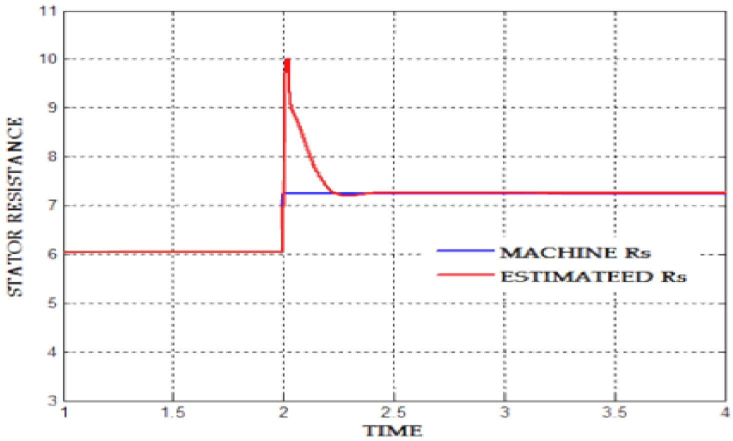

Fig.7. Actual and Estimated Stator Resistance for 30% change in R_s

Fig. 7 shows the performance of proposed stator resistance estimator for 30% change. The curve indicated in blue colour is the actual and the curve indicated in red colour is the estimated one. The estimated stator resistance closely tracks the actual one very well and settles down quickly as soon as the step change in stator resistance is effected at 1 sec.

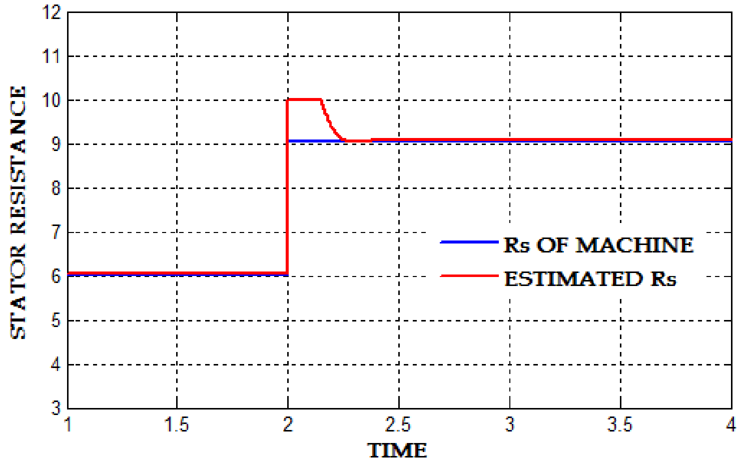

Fig. 8 shows the performance of proposed stator resistance estimator for 50% change. The curve indicated in blue colour is the actual and the curve indicated in red colour is the estimated one. The estimated stator resistance closely tracks the actual one very well and settles down quickly as soon as the step change in stator resistance is effected at 1 sec.

Table 1 Performance of Proposed Stator Resistance Estimator

$\%R_s$	Actual R_s in ohm	Estimated R_s in ohm	% Error	Settling time
10%	6.33	6.55	0.33	0.5
20%	7.236	7.260	0.33	0.5
30%	7.839	7.866	0.33	0.5
40%	8.442	8.471	0.34	0.37
50%	9.045	9.078	0.36	0.37

Table 1 shows the performance of stator resistance estimator for various changes in stator resistance. The error is found to be almost negligible.

V.CONCLUSION

In this paper, a different approach utilizing real and reactive power is proposed to estimate the Stator Resistance for flux estimator in direct torque controlled IM drives. The results are simulated using MATLAB/simulink 7.0. The performance of proposed R_s estimator is shown to track variation in R_s very well with good accuracy and settling time. Hence the proposed method is suitable for flux estimator in DTC drives.

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APPENDIX

The parameters of the three-phase induction motor used for simulation are presented below,

Parameters	***Values***	***Parameters***	***Values***
Rated Power	1.1kW	Stator Resistance (R_s)	6.03Ω
Rated voltage	415V	Rotor Resistance (R_r)	6.085Ω
Rated current	2.77A	Magnetizing Inductance (L_m)	0.4893H
Type	3 Ph	Stator Inductance (L_s)	0.5192H
Frequency	50Hz	Rotor Inductance (L_r)	0.5192H
Number of poles	4	Total Inertia (J_T)	0.011787Kgm^2
Rated Speed	1415RPM	Friction Coefficient (B)	0.0027Kgm^2/s

Nomenclature

$V_{ds}^s (V_{qs}^s)$	- Stator voltages d axis (q axis)	P	-real power in watts
$I_{ds}^s (I_{qs}^s)$	- Stator currents d axis (q axis)	Q	-reactive power in watts
$\psi_{ds}^s (\psi_{qs}^s)$	- Stator flux d axis (q axis)	ω	-Angular Frequency in rad/sec
R_s	- Stator resistance in ohms	ω_r	-Rotor Speed in rad/sec
θ_e	- Flux Angle in radians	L_s	-Stator Inductance in Henry
ψ_s	- Resultant Flux in wb	M	-Mutual Inductance in Henry
T_e	-Electromagnetic Torque	$I_{\max}$	-maximum quantity of phase current in Ampere

Superscript s-Stationary Reference Frame